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ABSTRACT

Two different uses of interactive graphics in computer-assisted instruction are described. Interactive graphics may be used as substitutes for physical devices and operations. An example is simulation of operating on man/machine interfaces, substituting interactive graphics for controls, indicators, and indications. Interactive graphics may also be used to explicate invisible processes. Examples are interactive graphics that allow the student to initiate animations of physical processes and interactive block diagrams that allow the student to learn the functional organization of complex devices. Projects are underway to test the effectiveness of these uses. (Author)

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DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

Technical Report No. 73

INTERACTIVE COMPUTER GRAPHICS FOR PERFORMANCE-STRUCTURE-ORIENTED CAI

July 1974

Joseph W. Rigney
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Carole A. King

Sponsored by

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Interactive graphics may also be used to explicate invisible processes. Examples are interactive graphics that allow the student to initiate animations of physical processes and interactive block diagrams

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Two different uses of interactive graphics in CAI are described. Interactive graphics may be used as substitutes for physical devices and operations. An example is simulation of operating on man/machine interfaces, substituting interactive graphics for controls, indicators, and indications.

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I. GRAPHICS AND IMAGERY

Several methods for generating computer graphics have become so inexpensive that this mode of interacting with the student can be afforded for CAI systems. PLATO IV's well-known plasma-panel terminal is an example. Vector generation, using CRT's is another, and is available in a number of different terminals. The user-packages that contain interpreters, editors, and other conveniences are making it relatively easy for non-programmers to produce graphics programs. This surely is a significant addition to the tools the educational technologist has at his disposal.

How should interactive computer graphics be used? What are their unique contributions? There must be many answers, but these are not altogether obvious. Some of the best work ever done in CAI was done with teletypes (Atkinson, 1974). It could be argued that the subject matter, reading, did not require interactive graphics. But, would the outcomes have been even more positive if interactive graphics had been available?

Man is good at mental images, a fact even the psychologists have discovered. Neisser (1967) says man's head is full of ghosts of previous experiences and of imagery experienced only in imagination. How does external imagery relate to mental imagery? More is known about words and mental imagery (Paivio, 1966). Subjects can generate mental imagery to remember words isolated from semantic context, as Bower (1970) and others have demonstrated in the laboratory, and as Raugh and Atkinson (1974) have confirmed in the educational environment, for paired-associates -- like vocabulary learning.

As Bower reminded us in his discussion of their "method of loci", the Greeks knew about using mental imagery to generate a context in which to embed items to be remembered. This clearly is a powerful mnemonic device. But, for learning the kinds of subject matter characteristic of technical training, or of a profession, this kind of ad lib imaging may not be so useful. Here, what is to be remembered is not a list of originally unrelated items, such as paired trigrams. It is material that already is a relational network. The problem is to get the student to image in terms of the relations and nodes in this network. Attneave (1974) discusses some of the issues involved. Knowing, he says, necessarily involves representation.

Man is such a good imager that he can communicate with his fellows about a complicated visual world very well with words. In a recent study (Rigney, et. al., 1972), a group of electronics technicians was given a week of practice in doing fault-localization from front-panel symptoms on a radar repeater. Using only teletypes for terminals, the technicians had to learn to "set" the controls on the front panel to test different circuit chains. All of these technicians already had been to a school in which they learned about the repeater; they had seen it and had operated it, and knew something about what went on inside. It is noteworthy that these technicians were able to troubleshoot this complicated device without having it present and without referring to pictures of it.

How, then, can interactive computer graphics be used to stimulate this remarkable representational system in ways that would facilitate learning and retention?

It is obvious that graphic images of various sorts are used in education. Textbooks are full of diagrams and pictures. Whole armories of

audio-visual devices and materials are found in the more affluent public schools, colleges, and universities. Even educational television still exists in its classic form. And, there are all sorts of schemes afoot, advanced by clever entrepreneurs, to tear the home viewer's TV set away from the ad agencies, to arouse him from his trance, and to put him to work on interactive educational games dispensed by TV tape recorders, response devices, and microprocessor controllers attached to the set.

There probably are countless volumes of information about the graphic arts, audio-visual media, and communication with pictures. It is not the purpose of this report to review this literature. Much of it seems to be in the realm of art, and dispenses experience-derived prescriptions, as necessarily must be the case. Some of it undoubtedly contains valuable information well worth attending to by anyone intending to use graphics.

The objectives of this report must be narrower in scope. Two types of interactive computer graphics have become available to this laboratory, one based on the plasma-panel and the other based on the vector-generator. These have been and are being put to use in research on cognitive variables. This report will describe computer graphics that have been developed using a graphics terminal with integral minicomputer, display processor, and core memory as a self-standing system. The vector-generation method is used in this device.

A subsequent report will be devoted to the description of interactive graphics which are based on the plasma-panel technique for generating graphics, and the touch-panel for sensing student responses (Rigney and Lutz, in press).

II. INTERACTIVE GRAPHICS AS SUBSTITUTES FOR PHYSICAL DEVICES AND OPERATIONS

It seems reasonable to suppose that various types of man-machine interfaces could be represented by computer graphics and that students could learn to perform procedural tasks by interacting with these graphics in a fashion analogous to interacting with the man-machine interface. There are several reasons for using graphics as substitutes here; some military equipment is becoming too expensive to use for training purposes, instructional techniques, e.g. external feedback, are easily incorporated, and computer graphics can be relatively easily developed and modified. Clearly, on the other hand, there is some loss of fidelity in iconic and dynamic features. Although iconic fidelity can be provided by photographs, the computer graphics probably never can replace all tactical equipment in military training. They are viewed as economical substitutes, to be used to bring students up to levels of learning at which they then can get maximum benefit from experience with the real equipment.

The effectiveness with which computer graphics can simulate physical devices is largely dependent upon the computer/terminal used. The student terminal used here contains a standard 16-bit word minicomputer, a display processor, 16K of core memory, a CRT, and a keyboard. The display processor is a special-purpose computer that produces lines on the CRT from display lists created by the minicomputer. A display list consists of a series of display commands, each of which either produces one vector, or calls a display subroutine which produces some general collection of vectors such as an alphabetic character or electronic symbol.

Since any or all commands can be changed between refreshing the CRT (every 1/40 second), rather sophisticated animation is possible.

It is important to point out that intelligent graphics terminals, i.e., terminals with integral minicomputers, display processors and high-speed memory, can be used to produce animated graphics that are not possible using ordinary terminals tied to a large remote processor by low baud-rate telephone lines. And the peripheral storage devices, e.g. floppy-disks, now available for stand-alone computer/terminals provide very ample capacity for storing student progress statistics and large input data lists. The disk used here has a capacity of 128K 16-bit words.

The physical devices that we are simulating for this investigation are two common types of equipment in the surface fleet: the AN/URC-32 and the AN/SPA66. The graphics for the AN/URC-32 will be described here.

The AN/URC-32 is a rack-mounted transceiver with ten different units stacked vertically, and with an eleventh unit, a high voltage power supply behind, at the base of the rack. Each unit has a front panel varying in complexity from a switch and an on-off light to several rotating knobs, frequency counters, multiple position switches, and meters.

The computer program which simulates front-panel hardware is called TASKTEACH. It utilizes interactive computer graphics to train students to troubleshoot complex equipment from information obtained from front-panel indicators. These include meters, lights, fuse indicators, and speakers. The program can also be used to perform interactive exercises with the student prior to the presentation of troubleshooting problems. These exercises include familiarizing the student with the physical configuration of the front panel, teaching him the proper sequences for

adjusting certain controls and tuning the equipment, teaching him to safely operate the equipment, and teaching the necessary control configurations for obtaining meaningful information from the front-panel indicators. The troubleshooting logic of TASKTEACH is an extension of logic that has been described elsewhere (Rigney, et. al., 1972).

While the basic troubleshooting logic has not changed significantly from teletype-based TASKTEACH, student inputs are now entered exclusively with a light-pen, program outputs are primarily pictorial rather than verbal, and student support features are more extensive and appropriate to the graphical mode of interaction.

In addition, the data base can now express extensive constraints on operator procedure. Thus, TASKTEACH can monitor the front-panel operations for conformance to safety conditions and sequence requirements. It can recognize the dependence of one control upon another; the manipulation of a control can invalidate certain adjustments and settings previously performed. And it now can actuate the random-access slide projector to show color slides of the actual front panel.

Finally, graphical TASKTEACH records student statistics on disk for subsequent analysis. The entire program set-up and data recording is accomplished by placing a particular disk in the proper disk-drive slot. Statistics for approximately one thousand student-hours can be recorded on one disk.

Since the viewing area on the CRT is relatively small, compared to a unit panel of the AN/URC-32, it was necessary to provide more detailed graphic representations of controls and indicators. Three levels of detail resulted: a top-level, simple outline of the entire device, used for accessing a particular unit front panel with a light pen; a second-

level display in which any unit front panel can be selected and displayed; and a third-level, detailed display of a control or an indicator, accessed by pointing with the light-pen at the simpler representation of that control or indicator on the unit front-panel display.

Using this procedure, the student can quickly access any part of the device front panels he desires to work on. He can do this nearly as rapidly as he can scan the actual device.

The troubleshooting process requires a means for accessing a graphic representation of any one of the front-panel controls, and for changing the control setting, while simultaneously viewing a meter or other indicator on any other unit panel. This was achieved by dividing the CRT screen into two, independent, viewing areas. The technician can bring a front-panel control into one area, and a related indicator into the other. He can then manipulate the control by pointing to desired switch settings with the light-pen. The control appears to change settings and, when pointed to with the light-pen, the indicator displays the indication which the actual equipment would exhibit under those conditions.

Auxiliary features are provided at the margins of the CRT display. A menu of system commands allows the student (1) to access colored slides of panels and panel details, (2) to check the settings of all controls in succession without going through the upper level displays, (3) to access information relating to progress during troubleshooting, (4) to initiate fault area replacement actions, and (5) to terminate a practice session.

Figures 1 through 4 illustrate some typical TASKTEACH displays of the AN/URC-32 transceiver.

At the beginning of each new problem, outlines of the transceiver are displayed on both the upper and lower halves of the screen, as shown

in Figure 1. When the student points to any of the units shown in the outline displays, detailed displays of the units instantly appear. Thus in Figure 2, the student has just pointed to the Sideband Generator Unit on both the upper and lower outline displays. The student can then proceed "down" to a more detailed display of a single control or indicator by pointing to the element desired, or he may progress "up" to the outline display by pointing to the • UP command displayed in the upper right-hand corner of each screen half. In Figure 3 the student has pointed to the Multimeter in the upper section, and the Meter Function switch in the lower section.

The current (initial) setting of the Meter Function switch is indicated by the small box around the "+130" setting. The student may now either check the Multimeter by pointing to it, or he may first reset the switch by pointing to the desired setting. In the latter case the box moves to the setting selected. The split screen format allows the student to easily check the indicator in various settings of the related control.

The upper and lower screen halves are entirely independent, and may each display any unit, control, or indicator. In Figure 4, the Power Amplifier has been selected in the upper screen half, and an unrelated control from a different unit is displayed below.

When the student obtains sufficient front-panel symptom information he indicates that he wishes to "replace" a component or group of components. He may then continue checking indications and make additional replacements, if necessary.

Figure 1. Initial TASKTEACH Display of AN/URC-32

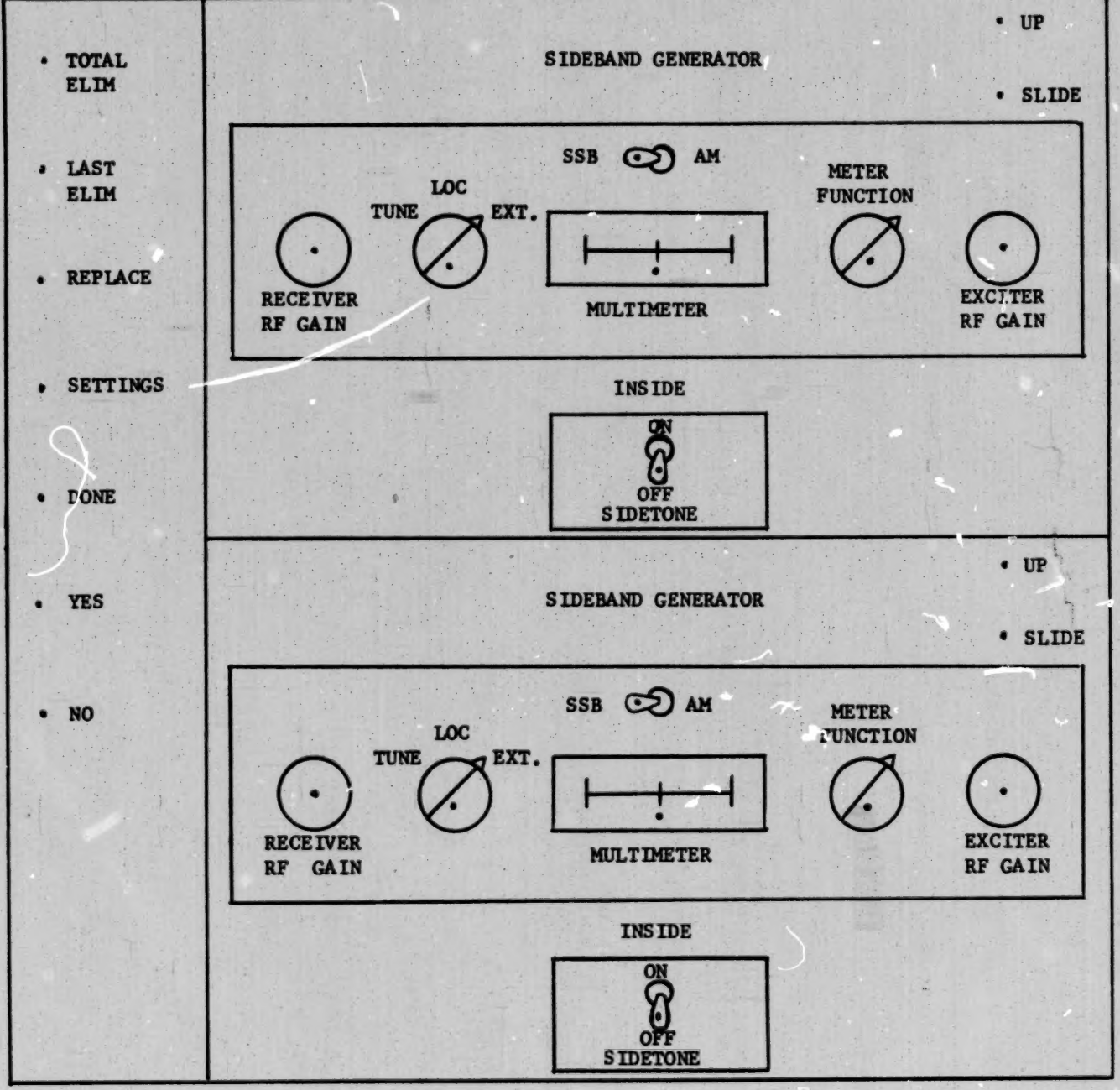


Figure 2. TASKTEACH Display of Sideband Generator Unit

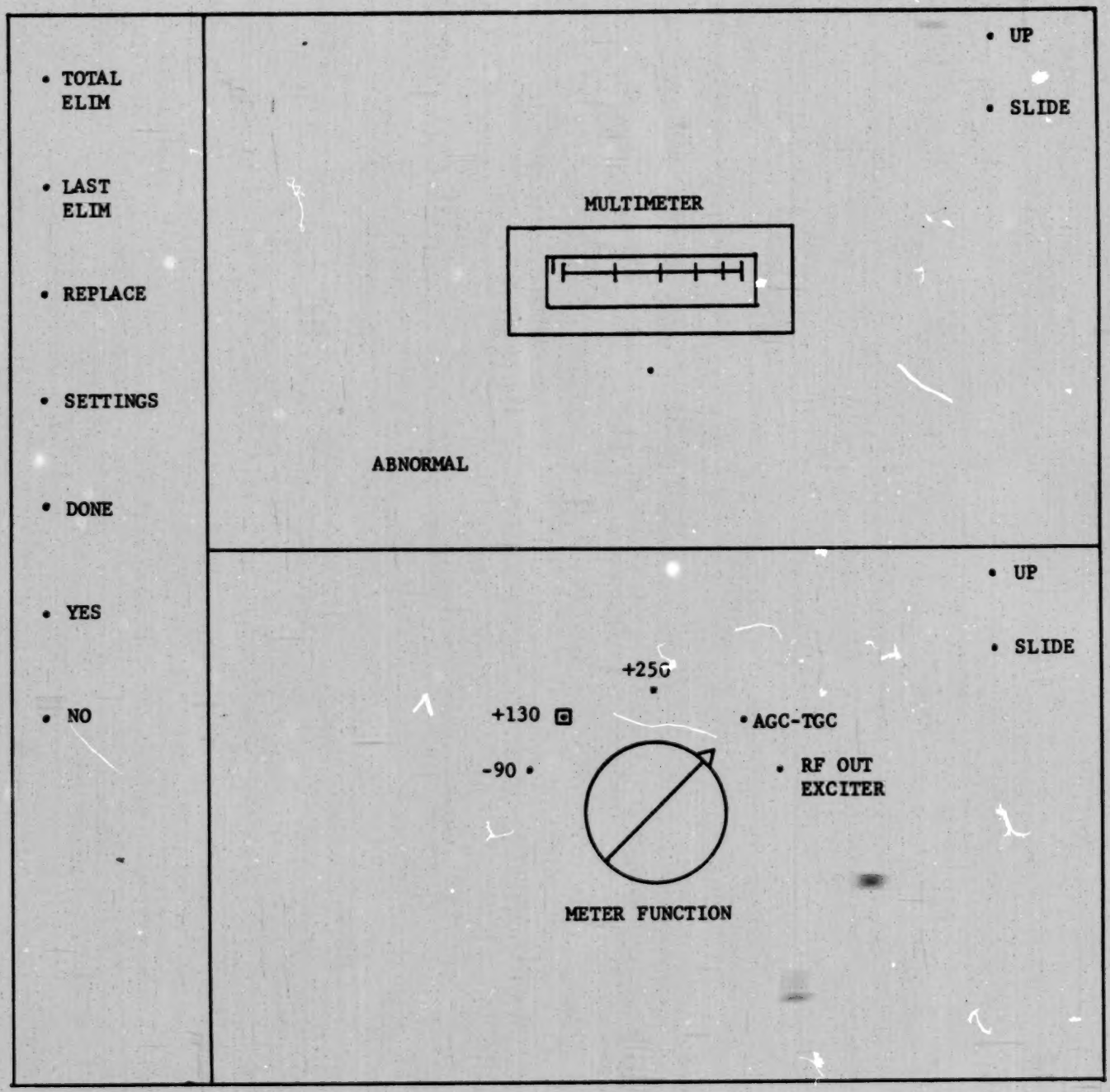


Figure 3. TASKTEACH Split Screen Usage

Figure 4. TASKTEACH Display of Power Amplifier Unit and Wattmeter Selector Switch

Input Procedure

Any equipment can be specified by a course preparer and be displayed by TASKTEACH. The input steps are as follows:

1. The desired displays are drawn on scaled graph paper.
2. Each drawing is described as a sequence of lines, circles, rectangles, etc. The data list for a drawing consists of numbers which specify the figure types, their X-Y locations, and scales. The standard figures in the TASKTEACH directory include alphanumeric characters, circles, rectangles, meters, toggle switches, rotary switches, lamps, and fuse indicators. Any other figures are constructed from straight line segments.
3. Each drawing is assigned a reference number and a picture type. The four types are EQUIPMENT, UNIT, CONTROL, and INDICATOR.

From the above data, TASKTEACH displays the "top" display in both screen halves, by interpreting the data list for that picture into a displayable form. When the student points at a lower level element, TASKTEACH retrieves the appropriate data list for that element and displays it. If the element is a control, TASKTEACH positions the settings-box to the current switch position.

III. INTERACTIVE GRAPHICS TO EXPLICATE INVISIBLE PROCESSES

Much of the teaching of the physical sciences and of the technologies derived from them is concerned with explaining invisible processes. At higher levels, the explanation is in terms of mathematical models. But, there are many occasions for teaching about a technology or its products to subjects who have not spent the better part of their youth learning mathematics. The bright high school graduates who find themselves studying electronics in some Class A school in the Navy, for example, might be less intimidated by the subject matter if more of it could be designed for visual imagery instead of being verbal descriptions or mathematical models. It might be helpful, for example, in learning the functional organization of an equipment, to have interactive graphics block-diagrams at hand. Or, it might be helpful in learning about transistors if the events occurring in the collector, base, and emitter could be illustrated with animated graphics. Making invisible processes visible would seem to be a worthwhile use of interactive computer graphics if the interaction requires the student to participate actively in the explication, and if the analogies are appropriate. The project described below was designed to employ graphics for these purposes.

These diagrams were developed to complement the front-panel graphics described above. Ideally, the student would alternate between troubleshooting from front panel symptoms and investigating the internal functional organization of the device to learn the sources of these symptoms. He should then be able to develop the mental representational

processes he needs to sustain this type of performance with less reference to external memories.

Of course, the emphasis is on exploring the learning potential of interactive block diagrams. Non-interactive block diagrams have been around for years and are found in every technical manual. The techniques of computer graphics allow the block diagram as a visual analog of functional organization to be converted into a powerful tool for learning by making the diagrams sensitive to student responses in various ways, providing for immediate external feedback, and allowing great flexibility and speed in accessing diagrams. For example, current software allows for nesting diagrams hierarchically to any depth, with each succeeding level accessed instantly with a light-pen.

The transceiver and radar repeater mentioned above are also the vehicles for these developments. Two computer programs are involved. The logic for displaying the diagrams and for interacting with the student is contained in a program called GAIN (Graphical Analysis of Interactive Networks). The logic for constructing the diagrams is contained in a program called TOGE (Towne's Own Graphical Editor).

GAIN is the last of a series of experimental programs that stemmed from earlier work with network description, which was a program written in extended BASIC, called MATGEN. However, the logic in GAIN is quite different, and it does not use the same data structures.

System Specifications

The primary functions of GAIN are as follows:

1. GAIN displays a hierarchical structure of block diagrams, i.e., each block in one diagram may be represented by a more detailed diagram, and so on. The data-base is stored on disk, and thus has the capacity to represent several hundred diagrams on one eight-

dollar disk. The main components of the block diagrams are:

a. "Blocks" which represent meaningful collections of hardware which perform identifiable functions;

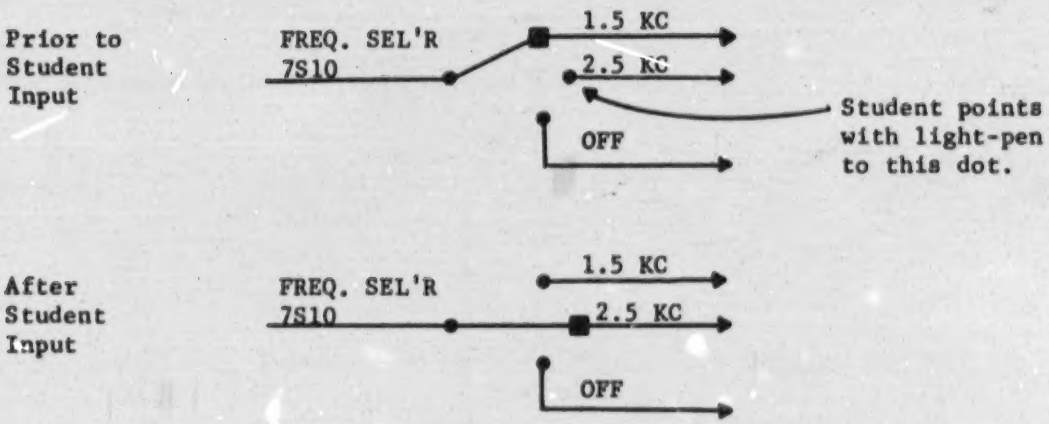
b. "Indicators" which exhibit the status of the equipment;

c. Switches which alter the functions (blocks) in the network, and which alter the functions currently monitored by various indicators.

A sub-diagram is displayed "instantaneously" when the student points to a block in one diagram which is more fully detailed in another diagram. All such blocks contain a "light-pen dot" to which the student points.

2. GAIN responds to student inputs to provide drill and practice in setting up various operational modes. The student points to desired switch settings, shown graphically as in the example below, to create an operational mode.

TYPICAL GAIN DISPLAY OF A SWITCH:



If a switch has multiple gangs, the student needs only to set one of the wafers; all ganged wafers change setting automatically.

The student may find all switches which he wishes to set on one diagram, or more typically he will utilize several diagrams. Since a light-pen dot appears in each block for which a detailed diagram exists, the student knows exactly where more detail is available even if he is not yet at all familiar with the equipment.

Figure 5 is the top level diagram for the AN/URC-32 receiver. It is obvious that more detailed diagrams may be viewed by pointing at any of the following:

a. SMO Module

b. RF Tuner Module

c. Sideband Generation Unit

d. Frequency Comparator

e. CW-FSK Unit

f. Audio & Control Unit

If the student calls in the diagram of the SMO Module, he sees the diagram shown in Figure 6. Within this diagram he may throw the Tune-Operate Switch, check the AFC meter, or call in the detailed diagram of the Sidestep Oscillator. Within the Sidestep Oscillator diagram, shown in Figure 7, he may set the Band Change Switch. To return to Figure 6 from Figure 7, the student touches the word "UP", displayed in the corner of the screen. A second touch restores the screen to Figure 5.

Once a switch is set, it will retain that setting, until changed, in all diagrams which contain the switch. Further, if the switch contains multiple gangs, those are automatically shown in their current setting. Finally, if a relay is directly

affected by a switch, it will change state on the CRT when the appropriate switch is set. Thus the student can make essentially the same actions on the CRT that he would make on the actual equipment, yet he is always viewing a block diagram representation of the hardware.

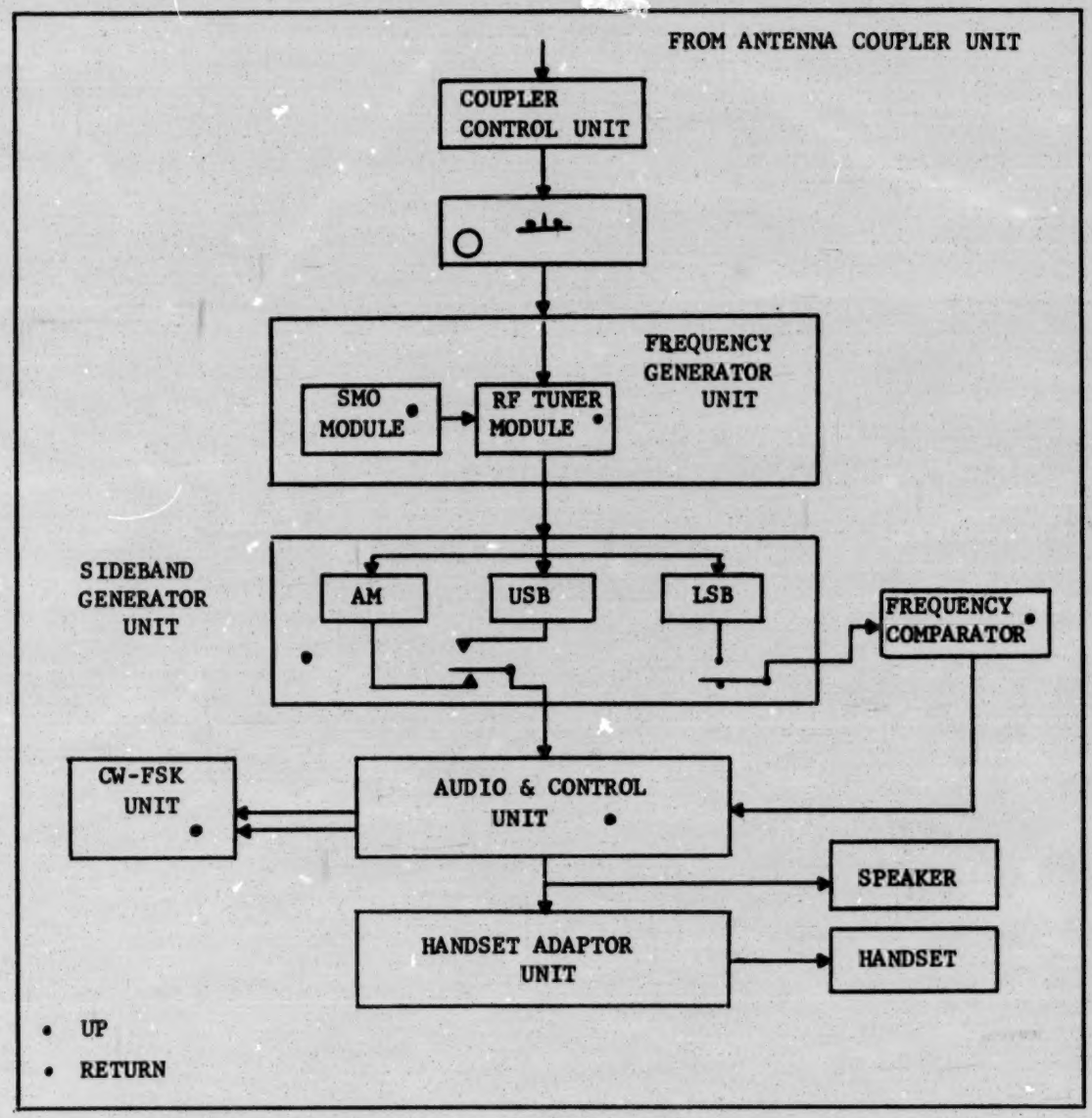


Figure 5. AN/URC-32 Receive Functions

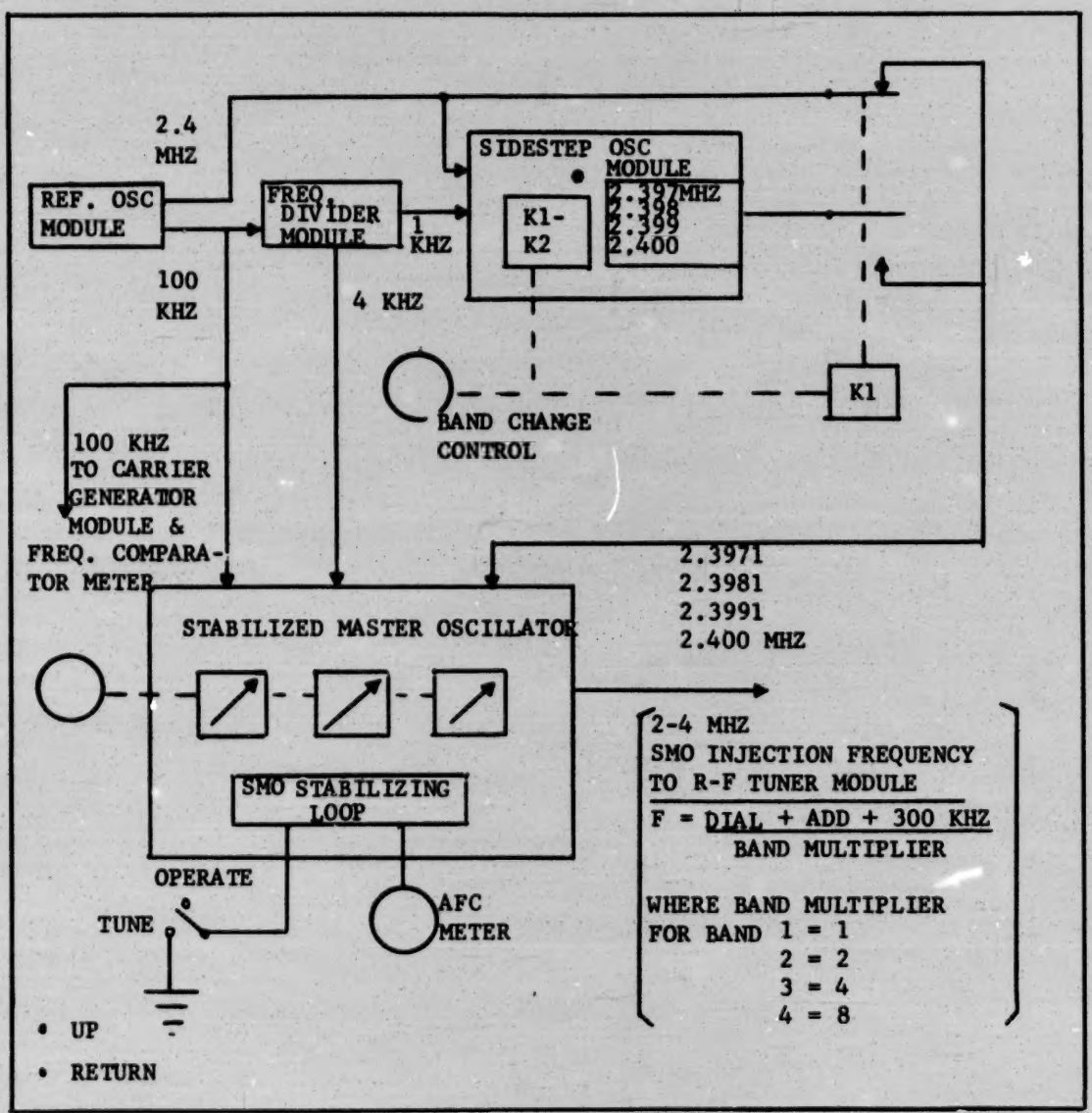


Figure 6. Stabilized Master Oscillator (SMO) Circuitry

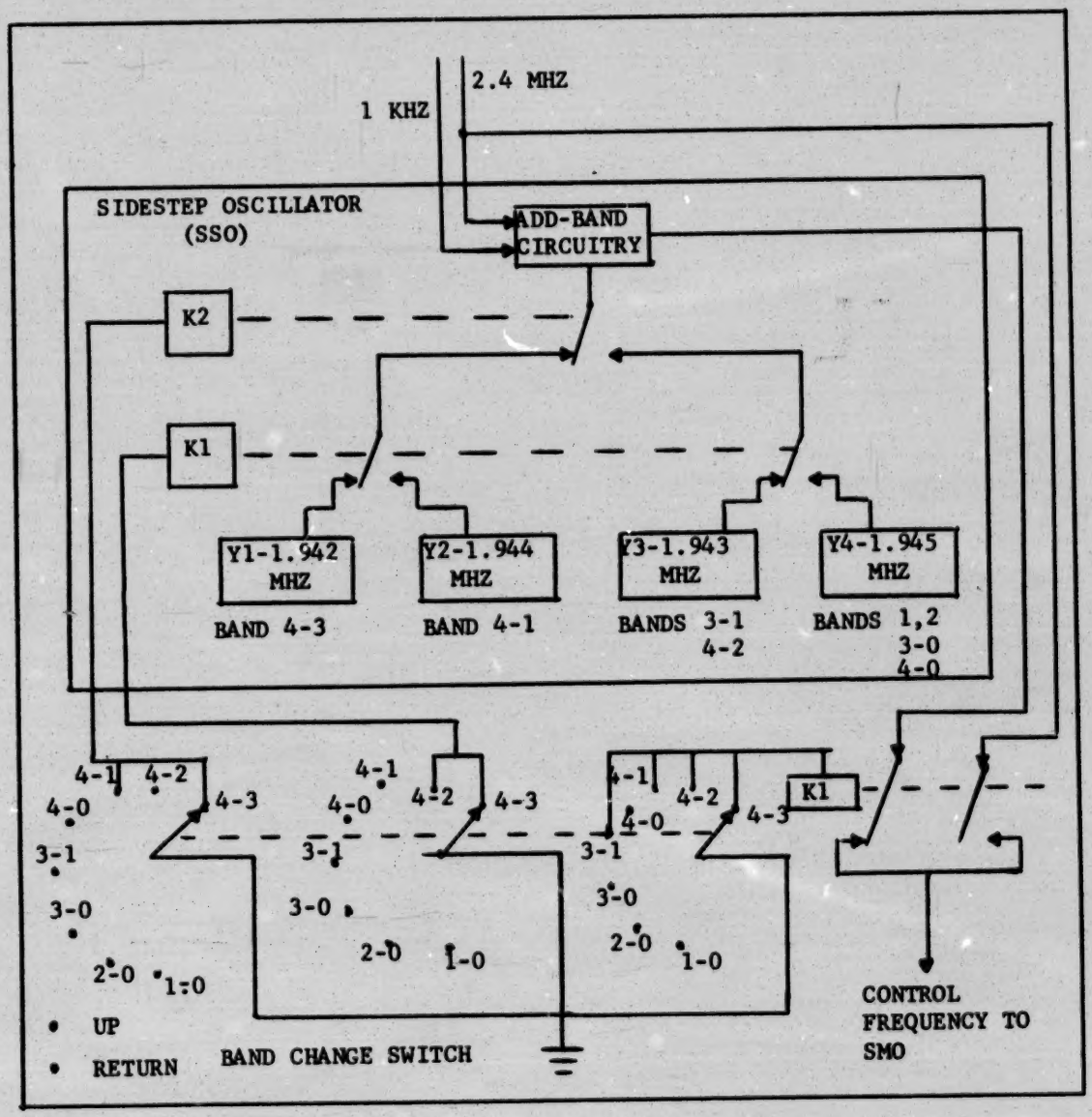


Figure 7. Sidestep Oscillator (SSO)

3. GAIN evaluates the correctness of student actions. The student indicates which front-panel configuration he is attempting to achieve by pointing to the desired mode from a list on the screen. Upon setting all desired switches he indicates that he is done with that mode. GAIN checks all switch settings and displays "ERROR" if the set-up is faulty. The student can then proceed to correct the setting(s). If the student cannot locate his error, he points to "HELP" displayed below "ERROR". GAIN then displays a circle around all switches which are improperly set, and records the fact that help was supplied.

4. GAIN displays function-mode relationships. At the touch of a key the student can indicate that he wishes to "highlight" the blocks involved in a particular mode. GAIN then brightens all blocks which are involved, and displays all other blocks dotted. The student can then attempt to bring those blocks into the network by setting appropriate switches.

Other Exercises. The foregoing describes the primary functions of GAIN, as currently programmed. Based upon these functions, two other types of drills can be developed:

1. Test Drill - The student creates a mode and checks an indicator. He then indicates what blocks have been monitored.

2. Troubleshooting Drill - The student performs a sequence of tests, receiving "NORMAL" and "ABNORMAL" symptoms at the various indicators. He attempts to isolate a simulated faulty block, inserted by GAIN. GAIN can randomly select any block as faulty.

Generality. A GAIN data-base can be developed for any equipment for which block diagrams are appropriate representations. The diagrams themselves are entirely flexible to the particular diagrammatic needs, while the program logic requires that some analog to a "SWITCH" exists which alters the way in which system modules are inter-connected. Continuous controls are either artificially "discrete-ized" or are ignored. The learning emphasis is on how functional elements are organized, how they may be altered by an operator, and how they may be monitored.

A GAIN data-base is not limited to any particular level. Effective exercises may be executed for multi-man, multi-device systems, or for a circuit composed of many components. Theoretically, a large-scale system can be successively partitioned into lower level data-bases, providing continuous training from the top level to the bottom. While this would involve the use of a number of data storage disks, the data on any one disk would cover a sufficiently large problem area that it would suffice for some days or weeks of training.

Because GAIN can view a multi-equipment system as a number of functions (blocks) which happen to be packaged separately, it can accommodate the addition of test equipment to a device's built-in state-monitoring indicators. The course preparer must anticipate where such equipment might be connected, such as at test points or jacks.

Relationship to TASKTEACH. TASKTEACH implements similar exercises based upon student actions on front-panel elements as they appear physically. The major differences between TASKTEACH and GAIN are:

a. TASKTEACH is concerned with sequence of actions, GAIN is not.
b. TASKTEACH is concerned with undesired consequences of certain actions, GAIN is not.

c. GAIN is concerned with illustrating the functional relationships among switches, blocks, and indicators; TASKTEACH is concerned with the physical relationships among these elements.

Thus the two programs can be extremely compatible in providing a complete training routine. This is especially true if care is taken to define the same functional elements (blocks) in the two programs. It may be that several blocks, when they fail, produce identical symptoms at the front panel. This simply means that the student cannot isolate the faulty block from front-panel indicators, not an uncommon result of design.

The GAIN Display Editor

The laborious procedures ordinarily required to design and program computer graphics can be significantly reduced by various forms of interpreters and editors. The interpreter-editor described below allows rapid construction of diagrams by simple commands entered at the terminal keyboard. This program is called TOGE.

TOGE is used to quickly produce displays of block diagrams for use by GAIN. This program can also be used to produce any other type displays since it is completely general purpose.

TOGE allows the user to construct displays at the keyboard, visually verifying the correctness of the display as it is built. The user can use display subroutines entered previously, and he can add new ones. While the display editor is completely general-purpose, it is expected that alternate disks of display subroutines will be created for different purposes. Thus one disk may contain display subroutines appropriate to block diagrams, another for electronic schematic diagrams, and another for electro-mechanical devices.

Once a display is created, possibly containing some portions built by calls to display subroutines, it is "dumped" into a special area of the computer and written on disk.

Constructing a Display. A graphics display is constructed by use of four function keys labelled ←, ↑, →, ↓. Each time one of these keys is struck, a cursor moves in the direction indicated. Upon positioning the cursor at a desired location, the user may strike function keys to either draw a solid line, dotted line, or invisible line from the last line to the cursor.

At any point in the development of a display the user may (1) change to smaller or larger scales, (2) save the existing display as a subroutine, (3) call in a display subroutine previously defined, or (4) clear the screen and start over.

As the display is developed errors may occur. TOGE includes functions to insert, change, or delete any portion of the display. This correction procedure may be done at any time, as often as necessary.

While TOGE may be used to construct displays for any purpose, it is often used to create block diagrams for GAIN. Since GAIN requires additional information about the blocks, switches, and indicators, a special software interface was added to TOGE. This logic allows the user to identify the elements of a diagram by pointing to them with the light-pen and entering their reference numbers at the keyboard. The user also points out which switch wafers are ganged together.

Upon identifying all the elements in the diagram, the user enters a SAVE command. TOGE then writes the display list and data lists for GAIN to disk.

Once written to disk, the data may be retrieved by GAIN upon a student's command to display a particular diagram. The student can then interact with the block diagram to practice set-ups or to explore the nature of the network.

IV. SUMMARY AND CONCLUSIONS

Before interactive computer graphics can be used, they must be generated. Without special programs, this is a most tedious process, since every figure that is not straight-sided and every alphanumeric character actually is drawn on the screen by successively repositioning and turning on or off a very small unit, a vector, or a dot. For instance, drawing the lower-case letter "d" may require repositioning a short vector eleven times.

A special interpreter-editor, which generates display instructions while the user, not necessarily a skilled programmer, is composing graphics, using keyboard function keys, is described. This program immeasurably facilitates the production of graphics display programs.

Several ways of using interactive computer graphics were described. The unique contribution of these graphics to CAI is implied by the word, interaction. Motion pictures or television can present moving images. But only interactive computer graphics allow the student to point at features embedded in these images to cause them to change in a variety of ways that could be useful to facilitate learning and remembering. Although it remains to be seen how valuable this unique feature will be, the new vistas that it opens for exploration are exciting.

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APPENDIX

TOGE Subroutine Log

Subroutine No.	Subroutine	
01	Light Pen Dot	•
02	No Op's	No Display
03	1/8" Square	□
04	Arrow Head - Right	→
05	Arrow Head - Up	↑
06	Arrow Head - Left	←
07	Arrow Head - Down	↓
10	Wire Cross-over - Right	1* 2
11	Left	2 1
12	Up	2
13	Down	1 2
14	Block, with Dot, Solid	8 × 4
15	Block, with Dot, Dotted	

* 1 represents beginning of subroutine; 2 represents end.

TOGE Functions

Function	Key(s)*
Move Cursor	← → ↑ ↓
Draw Visible Line	XMIT
Draw Dotted Line	5
Draw Invisible Line	6
Move Cursor "Back"	Ø
Move Cursor "Forward"	TAB
Delete Next Line or Character	DEL
Save Subroutine	2 (+ 2 Digits; 20 - 77)
Retrieve Subroutine	FORM (+ 2 Digits; 01 - 77)
Change Scale	4 (+ 1, 2, or 3)
Start Over	HOME
Page Transmit	CALL IN DATA DUMPER

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